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DESCRIPTION

LIQUID CRYSTAL DISPLAY DEVICE

TECHNICAL FIELD

The invention relates to a liquid crystal display device used as a display panel for a variety of electronic equipment such as a timepiece (watch and clock) and a portable information device.

BACKGROUND TECHNOLOGY

A timepiece for indicating digital display of time information such as hour, minute, and second, and calendar information such as date, days of the week, month, and year, by use of a liquid crystal display panel serving as a liquid crystal display device, has been in widespread use for wrist watches and clocks, provided with a crystal oscillation circuit.

There has also been in use a combination timepiece wherein an analog display indicating time information by the hands of the watch is used in combination with digital display indicating time information and calendar information in numbers and letters.

Further, there has been proposed an analog watch for selectively displaying markers in various patterns, or for displaying simulated hands for an hour hand, a minute hand, and a second hand, by making up the dial thereof based on a liquid crystal display panel (refer to, for example, Japanese Patent Laid-open S 54 - 153066).

In addition to a timepiece, in other electronic equipment such as a cellular phone, portable electronic calculator and portable game

machine, a reflection-type liquid crystal display device which is compact and demands extremely low power consumption is widely used as a display panel displaying required information (textual or image information).

In such a conventional liquid crystal display panel serving as a liquid crystal display device, a liquid crystal cell filled with liquid crystals is sandwiched between two transparent substrates each having an electrode on an inner facing surface thereof, and an upper polarizing film and a lower polarizing film are disposed, respectively, on the external opposite surface of each transparent substrate. If an electric field is applied to the liquid crystals by applying a voltage to the pair of electrodes on the transparent substrates holding the liquid crystal cell therebetween, the optical property of the liquid crystals is changed, thereby locally controlling transmission and absorption of light falling on the liquid crystal display panel such that a predetermined display is effected.

Each of the upper polarizing film and the lower polarizing film is a polarizing film absorbing the light linearly polarized in the direction orthogonal to the transmission axis thereof.

In the case of a watch using the conventional liquid crystal display panel described above, time information and calendar information are displayed in dark against a white background in the normally white mode that is common.

However, by simply displaying time information and calendar information in dark against the white background as described in the foregoing, neither variation in design nor fun of use can be offered, leading to rapid decline in product popularity among consumers.

Probably as a result, consumption of digital watches has recently been on the decline, and neither combination timepieces nor analog watches with liquid crystal display panels have received market acceptance.

As in the case of a timepiece, liquid display panels for other electronic equipment generally display various information in dark against the white background. Some can display in reverse, but these are still poor in variation in design and fun of use.

The invention has been developed in light of the present situation as described, and an object thereof is to provide a liquid crystal display device capable of displaying information brightly and clearly in an electronic equipment such as a timepiece and providing variation in design.

DISCLOSURE OF THE INVENTION

To this end, the invention provides a liquid crystal display device which is made up as follows.

An absorption-type polarizing film for absorbing the light linearly polarized in the direction orthogonal to the transmission axis thereof is disposed on the visible side of the liquid crystal cell, having a liquid crystal layer sealed in between a pair of transparent substrates, each having an electrode on the inner facing surfaces thereof, while a reflection-type polarizing film for reflecting the light linearly polarized in the direction orthogonal to the transmission axis thereof is disposed on the side of the liquid crystal cell opposite from the visible side thereof.

Further, a color filter is disposed on the visible side of the absorption-type polarizing film, or between the absorption-type

polarizing film and the reflection-type polarizing film.

Further, a light absorption film may be disposed on the side of the reflection-type polarizing film, opposite from the visible side thereof. Further, a light scattering film may be disposed on the visible side of the absorption-type polarizing film. Further, a backlight may be disposed on the side of the reflection-type polarizing film, opposite from the visible side thereof. In the latter case, a translucent film may be disposed between the reflection-type polarizing film and the backlight. An absorption-type polarizing film may be used as the translucent film.

In the liquid crystal display panel having the backlight disposed therein, a light scattering film may be disposed on the visible side of the absorption-type polarizing film.

In the aforementioned liquid crystal display panels, the absorption-type polarizing film is, preferably, disposed on the visible side of the liquid crystal cell such that the transmission axis of the absorption-type polarizing film is parallel with the direction of the long axes of liquid crystal molecules located on the visible side of the liquid crystal layer in the liquid crystal cell, while the reflection-type polarizing film is, preferably, disposed such that the transmission axis thereof is parallel with, or orthogonal to the direction of the long axes of liquid crystal molecules located on the side opposite from the visible side of the liquid crystal layer in the liquid crystal cell.

Alternatively, the absorption-type polarizing film is disposed on the visible side of the liquid crystal cell such that the transmission axis of the absorption-type polarizing film may be orthogonal to the direction of the long axes of liquid crystal molecules located on the

visible side of the liquid crystal layer in the liquid crystal cell while the reflection-type polarizing film is disposed such that the transmission axis thereof may be in parallel with, or orthogonal to the direction of the long axes of liquid crystal molecules located on the side opposite from the visible side of the liquid crystal layer in the liquid crystal cell.

(These conditions are particularly indicated when using a twisted nematic liquid crystal layer having a twist angle of 90° .)

As the color filter of the aforementioned liquid crystal display panel, it is preferable to use the following:

1) a selective transmission color filter for transmitting a light component substantially at a specified wavelength only;

2) a color polarizing film capable of transmitting a component of the light linearly polarized in the direction orthogonal to the transmission axis thereof, at a specified wavelength only, and absorbing light components of the linearly polarized at other wavelengths while transmitting all components of the light linearly polarized light in the direction parallel with the transmission axis thereof;

3) a dielectric multi layer film capable of reflecting a light component of incoming light having a specified wavelength, while transmitting light components of the incoming light at other wavelengths.

In the case of using a selective transmission color filter, selective transmission color filters in plural colors which transmit light components at different specified wavelengths can be arranged on the same plane.

Additionally, selective transmission color filters in three colors at specified wavelengths of light components in red, green and blue are arranged in a given order repeatedly and regularly, so that multi-colored metallic color display by an additive color mixture is made possible.

Moreover, selective transmission color filters in three colors at specified wavelengths in the regions of wavelength of light components in cyan, magenta and yellow are arranged in a given order repeatedly and regularly, so that multi-colored metallic color display by a subtractive color mixture is also made possible.

The liquid crystal layer of said liquid crystal cell may be composed of any from among a twisted nematic liquid crystal layer, a supertwisted nematic liquid crystal layer, and a guest host liquid crystal layer.

The color filter of the liquid crystal display panel may be disposed between the absorption-type polarizing film and the liquid crystal cell or may be disposed between the liquid crystal cell and the reflection-type polarizing film. Alternately, the color filter may be disposed between the transparent substrates making up the liquid crystal cell and the liquid crystal layer.

In the liquid crystal display device according to the invention, light falling on the liquid crystal display panel from the visible side thereof is turned to linearly polarized light by the absorption-type polarizing film, and the linearly polarized light is either twisted or not twisted when transmitted through the liquid crystal cell of the liquid crystal display panel, depending on whether a voltage is applied or not between the electrodes in parts of the liquid crystal cell through which

the linearly polarized light is transmitted. If the light is linearly polarized in the direction parallel to the transmission axis of the reflection-type polarizing film upon reaching the reflection-type polarizing film, the linearly polarized light is transmitted through the reflection-type polarizing film. However, if the light is linearly polarized in the direction crossing the transmission axis of the reflection-type polarizing film at right angles upon reaching there, the linearly polarized light undergoes specular reflection by the reflection-type polarizing film, and is sent back to the visible side.

Further, since the color filter is disposed in the optical path of the linearly polarized light, the linearly polarized light is colored. Accordingly, parts where the linearly polarized light is reflected appear as a bright and colored display in a metallic tone or mirror-like tone, while parts where incoming light is transmitted through the reflection-type polarizing film are indicated in the color of the background of the parts (the colors of components inside the timepiece, or in black, white, or other optional colors in the case wherein the light absorption film, the translucent film, and so forth are installed). Accordingly, due to sharp contrast between these parts, time information and calendar information can be indicated in bright and colored display.

Thus, the invention can provide a liquid crystal display device for manufacturing a timepiece and other electronic equipment having variation in design.

Further, by disposing the light scattering film on the visible side of the absorption-type polarizing film of the liquid crystal display panel described above, light reflected through specular reflection by

the reflection-type polarizing film is scattered, turning colored display of a metallic tone or mirror-like tone to a more delicate tone of color so as to be seen with more ease while widening a viewing angle as well.

If the backlight is installed on the side of the reflection-type polarizing film opposite from the visible side, a half of light falling on the reflection-type polarizing film when the backlight is lit up is transmitted therethrough even in a dark environment such as at night, and is turned to linearly polarized light to fall on the liquid crystal cell. There will be created parts where the linearly polarized light is twisted and parts where the linearly polarized light is not twisted depending on whether a voltage is applied between the electrodes of the liquid crystal cell or not, and as a result, time information and calendar information can be indicated distinctly in color display by a difference in brightness between parts where the linearly polarized light is transmitted through the absorption-type polarizing film and parts where the light linearly polarized is absorbed by the absorption-type polarizing film, and by coloring of the linearly polarized light by the agency of the color filter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a shematic sectional view illustrating a construction of a first embodiment of a liquid crystal display device according to the present invention, and Figs. 2 and 3 are shematic sectional views illustrating respective modified examples;

Fig. 4 is a shematic sectional view of a liquid crystal cell incorporated therein as in Fig. 1 showing except a mid-portion, and

Figs. 5-7 are sectional views illustrating respectively different examples of liquid crystal cells with a color filter incorporated therein and similar to Fig. 4;

Fig. 8 is a shematic sectional view illustrating the construction of the liquid crystal display device using the liquid crystal cell as shown in one of Figs. 5-7;

Figs. 9 and 10 are views for explaining the principles of colored display by the liquid crystal display device shown in Fig. 1;

Figs. 11-17 are shematic sectional views illustrating constructions of a second to eighth embodiments of the liquid crystal display device shown in Fig. 1;

Figs. 18 and 19 are views for explaining the construction of a ninth embodiment of the liquid crystal display device according to the present invention and the principles of colored display thereby;

Figs. 20 and 21 are views for explaining the construction of a tenth embodiment of the liquid crystal display device according to the present invention and the principles of colored display thereby;

BEST MODE FOR CARRYING OUT THE INVENTION

A best mode for carrying out the invention will be now described with reference to the attached drawings.

First Embodiment

First, a first embodiment of a liquid crystal display panel serving as a liquid crystal display device according to the present invention and a different example are described with reference to Figs. 1 to 10. These figures exaggerate the thickness of and spacing

between respective components.

Fig. 1 is a schematic sectional view illustrating the construction of the liquid crystal display panel 10, and Fig. 4 is a schematic sectional view of a liquid crystal cell 12 incorporated therein, in which a mid-portion is cutaway.

As shown in Fig. 1, the liquid crystal display panel 10 is made up of the liquid crystal cell 12, an absorption-type polarizing film 14 disposed on the visible side (the upper side in the figure) of the liquid crystal cell 12, a reflection-type polarizing film 16 disposed on the side opposite from the visible side (the underside in the figure) of the liquid crystal cell 12 and a color filter 18 disposed between the absorption-type polarizing film 14 and the liquid crystal cell 12.

As shown in Fig. 4, the liquid crystal cell 12 is made up by adhering together a pair of substrates 1, 2, made of transparent insulating material such as glass, with a sealant 4 disposed on the periphery thereof, so as to seal a liquid crystal layer 3 in a gap formed between the pair of the substrates to be interposed therebetween. Transparent electrodes 5, 6, made of indium tin oxide (ITO) and so forth, are formed on the inner faces of the pair of the substrates 1, 2, facing each other, respectively, and at least one of the electrodes is formed in such a pattern as is required for displaying time information and calendar information (for displaying numbers, generally, in the seven-segment display pattern).

The liquid crystal layer 3 is composed of twisted nematic (TN) liquid crystals having a twist angle of 90 degrees, and alignment treatment is applied to the surface of the respective substrates 1, 2 and the respective electrodes 5, 6, on the side in contact with the liquid

crystal layer 3, such that liquid crystal molecules are aligned in predetermined directions.

The absorption-type polarizing film 14 disposed on the visible side of the liquid crystal cell 12 is a sheet-shaped member for transmitting the light linearly polarized in the direction parallel with the transmission axis thereof, and absorbing the light linearly polarized in the direction orthogonal to the transmission axis thereof.

The reflection-type polarizing film 16 disposed on the side of the liquid crystal cell 12 opposite from the visible side is a sheet-shaped member for transmitting the light linearly polarized in the direction parallel with the transmission axis thereof, and reflecting the light linearly polarized in the direction orthogonal to the transmission axis thereof. As the reflection-type polarizing film 16, an optical film, for example, DBEF (trade name), manufactured by Sumitomo Three M Co., Ltd., is used.

The absorption-type polarizing film 14 is disposed such that the transmission axis thereof is parallel with the direction of the long axes of liquid crystal molecules located on the visible side of the liquid crystal layer 3 in the liquid crystal cell 12.

Also, the reflection-type polarizing film 16 is disposed such that the transmission axis thereof is parallel with the direction of the long axes of liquid crystal molecules located on the side opposite from the visible side of the liquid crystal layer 3 in the liquid crystal cell 12.

Consequently, the transmission axis of the absorption-type polarizing film 14 crosses that of the reflection-type polarizing film 16 at a right angle.

In Fig. 1, the direction of stripes on the absorption-type polarizing film 14 and that of stripes on the reflection-type polarizing film 16 indicate the direction of the respective transmission axes, lateral stripes on the absorption-type polarizing film 14 indicating that the direction of the transmission axis thereof is parallel to the plane of the figure, while vertical stripes on the reflection-type polarizing film 16 indicating that the direction of the transmission axis thereof is perpendicular to the plane of the figure.

The color filter 18 disposed between the absorption-type polarizing film 14 and the liquid crystal cell 12 is a selective transmission color filter (also called an absorption-type filter) for transmitting a light component substantially at a specified wavelength only, and for absorbing light components at other wavelengths. Accordingly, light transmitted through this color filter is colored in a specified color.

For example, a pigment-dispersion coating film, prepared by dispersing a pigment in an organic resin and blending both together, is used for the selective transmission color filter. As the pigment-dispersion coating film can be formed by a coating method or a printing method, the same can be fabricated to a surface (for example, in Fig. 1, on the surface of the absorption-type polarizing film 14, opposite from the visible side, or in Fig. 6, on the outer surface of the substrate 1 disposed on the visible side of the liquid crystal cell 12) of one of the existing constituent members by means of the coating, without requiring any additional constituent member. Of light falling on the pigment-dispersion coating film, a light component at a specified wavelength only is transmitted therethrough, and light

components at other wavelengths are absorbed thereby.

Placement of the color filter 18 is not limited to the position shown in Fig. 1, and may be located anywhere on the visible side of the reflection-type polarizing film 16 which is composed of the liquid crystal display panel 10.

Accordingly, the color filter 18 may be disposed on the visible side (on the external side) of the absorption-type polarizing film 14 as shown in Fig. 2, or between the liquid crystal cell 12 and the reflection-type polarizing film 16 as shown in Fig. 3.

Otherwise, a liquid crystal cell 12CF with a color filter incorporated therein may be substituted for the liquid crystal cell 12 as shown in Fig. 5 or Fig. 6, and then, the liquid crystal display panel 10 can be made up simply by disposing the absorption-type polarizing film 14 and the reflection-type polarizing film 16, on the opposite sides of the liquid crystal cell 12CF, with the color filter incorporated therein as shown in Fig. 8.

In such a case, the color filter 18 may be formed by applying the pigment-dispersion coating film to the inner surface of the substrate 1 disposed on the visible side of the liquid crystal cell 12CF as shown in Fig. 5, or by applying the pigment-dispersion coating film to the inner surface of the substrate 2 disposed on the side of the liquid crystal cell 12CF opposite from the visible side as shown in Fig. 6.

The transparent electrode 5 or 6 is formed on the surface of the color filter 18 thus formed, in contact with the liquid crystal layer 3, however, the color filter 18 may be formed instead on the entire surface of the substrate 1 with the electrode 5 formed thereon, in

contact with the liquid crystal layer 3, or on the entire surface of the substrate 2 with the electrode 6 formed thereon, in contact with the liquid crystal layer 3.

In the case of using a selective transmission color filter as the color filter 18, selective transmission color filters in plural colors which transmit light components at a different specified wavelength can be arranged on the same plane.

Additionally, selective transmission color filters in three colors at specified wavelengths of light components in red, green and blue are arranged in a given order repeatedly and regularly, so that multi-colored metallic color display by an additive color mixture is made possible.

For instance, the liquid crystal 12CF with a color filter incorporated therein is composed as shown in Fig. 7, and a red pigment-dispersion coating film (R) at a specified wavelength of 600-700nm, a green pigment-dispersion coating film (G) at a specified wavelength of 500-600nm and a blue pigment-dispersion coating film (B) at a specified wavelength of 400-500nm, can be arranged on the inner surface of the substrate 1 as the color filter 18 so as to be in the order of R, G, B, repeatedly and regularly. An independent electrode element serving as the electrode 5 is formed on each of the pigment-dispersion coating films. The pigment-dispersion coating films R, G and B in three colors constitute one pixel, and ON/OFF of the voltage application between the electrode element on each pigment-dispersion coating film and the common electrode 6 opposite thereto is controlled, thereby an additive color mixture is achieved.

The example of providing the color filter 18 by the three-

colored pigment-dispersion coating films R, G and B on the inner surface of the substrate 1 on the visible side of the liquid crystal cell 12 is described above. However, it is needless to say that the color filter 18 can be provided on the inner surface of the substrate 2 opposite to the visible side. In such a case, the electrode 6 formed thereon is formed to be a electrode element corresponding to each of the pigment-dispersion coating films R, G and B, and the electrode 5 on the side of the substrate 1 is formed to be a common electrode.

The color filter 18 by the three-colored pigment-dispersion coating films R, G and B described above can be formed on the outer surface (the surface opposite to the liquid crystal layer 3) of either of the substrate 1 or 2. However, it is not favorable to form the color filter 18 as described above because when the pigment-dispersion coating films at a plurality of different specified wavelengths are arranged on the same plane, a subtractive color mixture is occurred relative to the incoming light from the slanting direction depending on the thickness of the substrate 1 or 2, thereby decreasing purity of color and brightness of the light.

Selective transmission color filters in three colors (cyan, magenta, yellow) which transmit light components at specified wavelengths in the regions of wavelength of cyan (400-600nm), magenta (400-500nm and 600-700nm) and yellow (500-700nm) can be arranged as the color filter 18 in a given order repeatedly and regularly. In such a case, multi-colored metallic color display by a subtractive color mixture is made possible.

Now, the principles of colored display by the liquid crystal display panel 10 shown in Fig. 1 are described with reference to Figs.

9 and 10.

In these figures, the lateral stripes on the absorption-type polarizing film 14 and the vertical stripes on the reflection-type polarizing film 16 indicate the direction of the respective transmission axes either parallel to the plane of the figure, or perpendicular to the plane of the figure as described with reference to Fig. 1. Longer solid lines with an arrow at one end thereof indicate the direction of light rays, and shorter solid lines with an arrow at opposite ends thereof indicate the direction of the light linearly polarized after the light rays pass through respective constituent members; ones shown oriented sideways being in the direction parallel to the plane of the figure, and ones shown oriented vertically being in the direction perpendicular to the plane of the figure.

As described in the foregoing, the liquid crystal layer 3 of the liquid crystal cell 12 is composed of the twisted nematic (TN) liquid crystals having the twist angle of 90 degrees, and the color filter 18 is the selective transmission color filter capable of transmitting a light component in yellow only, and absorbing light components in colors other than yellow.

Fig. 9 shows the background part when no voltage is applied between the electrodes 5 and 6 of the liquid crystal cell 12 (in an OFF state), where the direction of the light linearly polarized transmitted through the liquid crystal cell 12 is twisted by 90° (phase modulation) due to the twisting function of the liquid crystal layer 3 (Fig. 6).

Fig. 10 shows display parts for characters and so forth when a voltage is applied between the electrodes 5 and 6 of the liquid crystal cell 12 (in an ON state), where incoming linearly polarized light is

transmitted as it is through the liquid crystal cell 12 without the polarized direction thereof being twisted (phase modulation) as the liquid crystal layer 3 of the liquid crystal cell 12 loses the twisting function thereof with the liquid crystal molecules being set upright.

A half of light directed through the liquid crystal display panel 10 from the visible side (the upper side in the figure) is absorbed by the absorption-type polarizing film 14. The remaining half thereof is transmitted through the absorption-type polarizing film 14, and turned to the light linearly polarized in the direction parallel with the plane of the figure, falling then on the color filter 18.

Components of the linearly polarized light, in colors other than yellow, are all absorbed by the color filter 18 regardless of the ON/OFF stateof the liquid crystal cell 12. A component of the linearly polarized light, in yellow, is transmitted through the color filter 18, falling on the liquid crystal cell 12.

With the liquid crystal cell 12 in the OFF state as shown in Fig. 9, the linearly polarized light in yellow falls on the reflection-type polarizing film 16 after the direction thereof is twisted by 90°, and oriented in the direction perpendicular to the plane of the figure while transmitted through the liquid crystal cell 12. Since the linearly polarized light in yellow is in the same direction as that of the transmission axis of the reflection-type polarizing film 16, same is transmitted through the reflection-type polarizing film 16, so that the background can be seen in dark (the colors of components inside a timepiece in the case of the liquid crystal display panel 10 being installed in the timepiece) from the visible side.

On the other hand, with the liquid crystal cell 12 in the ON

state as shown in Fig. 10, the linearly polarized light in yellow falls on the reflection-type polarizing film 16 with the polarized direction thereof remaining oriented in the direction parallel with the plane of the figure after being transmitted through the liquid crystal cell 12 without the direction thereof being twisted. Since the linearly polarized light in yellow has an oscillation direction oriented in the direction crossing the transmission axis of the reflection-type polarizing film 16 at a right angle, same undergoes specular reflection by the reflection-type polarizing film 16. As the reflected light of the linearly polarized light in yellow is sent back toward the visible side along the optical path in the direction reverse to that in which the linearly polarized light in yellow has come in, bright display in a yellow metallic tone can be indicated. Such display indicates a view in the same way as if a yellow color filter was placed on a mirror.

Accordingly, by applying a voltage between the electrodes of the liquid crystal cell 12 only in the display parts for characters for displaying information, bright display of characters can be indicated in a yellow metallic tone (similar to the color of gold) against the dark background, enabling the interior of a timepiece to be seen through.

Thus, with the liquid crystal display device according to the invention, substantially all light falling on the liquid crystal display panel 10, and colored, is reflected in regions for displaying information such as characters, enabling bright and colored display to be indicated in a metallic tone.

On the other hand, in the regions of the background for displaying information, light falling on the liquid crystal display panel 10 is transmitted through the reflection-type polarizing film 16, so

that the side of the reflection-type polarizing film 16, opposite from the visible side, can be seen through. As a result, display as a whole indicates characters and the like brought into relief in a colored and metallic tone.

Also, by disposing the reflection-type polarizing film 16 such that the transmission axis thereof crosses the direction of the long axes of the liquid crystal molecules on the side of the liquid crystal layer 3, opposite from the visible side, at a right angle, the transmission axis of the absorption-type polarizing film 14 is caused to be parallel with that of the reflection-type polarizing film 16, inverting the display condition described above by way of example, so that characters and so forth can be displayed in a fashion enabling the interior to be seen against the background in a yellow metallic tone.

If a color filter 18 capable of transmitting a light component in a different color is used, either the display parts or the background part can be indicated in display in the metallic tone of an optional color.

Accordingly, the invention can provide a liquid crystal display device having wide variation in design and offering some fun of use as well, in marked contrast to conventional liquid crystal display device for displaying various information in black against the background in white.

Also, for the liquid crystal display panel described above, a liquid crystal display panel of the dot matrix display mode may be adopted in order to display characters or graphics arbitrarily, or to display given graphics selectively by forming a electrode of a liquid crystal cell into many kinds of graphic patterns.

With any of the liquid crystal display panels wherein the color filter 18 is disposed in various positions as shown in Figs. 2, 3, and Figs. 5 to 8, respectively, the function of the respective liquid crystal display panels for colored display as described remains the same although a position where light falling on the liquid crystal display panel is colored by the color filter 18 is different in each case.

When the color filter 18 is constructed so that a pixel consists of three-colored pigment-dispersion coating films R, G and B as shown in Fig. 7, display by specular reflection light in which light components in three colors, i.e., red, green and blue, are given an additive color mixture per pixel can be achieved, thereby enabling color display of arbitrary characters or graphics in multi-colored metallic tone.

A case where the liquid crystal layer 3 sealed in the liquid crystal cell 12 is composed of the twisted nematic (TN) liquid crystals having a twist angle of 90° has been described in the foregoing by way of example, however, TN liquid crystals having a twist angle of less than 90°, supertwisted nematic (STN) liquid crystals having a twist angle in the range from 180° to 270°, or guest host liquid crystals and so forth may be used instead.

With the use of the supertwisted nematic liquid crystals, the transmission-voltage curve of the liquid crystal layer 3 can be made steeper, thereby increasing contrast.

When the liquid crystal layer 3 has a function of twisting the direction of linearly polarized light transmitted therethrough by the effect of phase modulation, the absorption-type polarizing film 14 and the reflection-type polarizing film 16, disposed on the opposite sides

of the liquid crystal cell 12, are arranged such that the transmission axes of both the films in parallel with each other, or cross each other at an angle equal to the twist angle of the liquid crystal layer 3 (at right angles if the twist angle is 90°).

The guest host liquid crystals are mixed type liquid crystals made by dissolving a dichrotic dye as solute into liquid crystals as solvent. If the alignment condition of the guest host liquid crystal molecules is changed by applying an electric field thereto, the alignment of the dichrotic dye can be controlled following movement of the liquid crystal molecules, indicating display by modulating absorption of light incoming from a given direction.

By sealing the guest host liquid crystals in the liquid crystal cell 12 of the liquid crystal display panel 10, it is possible to show the regions for displaying information such as characters in a colored display condition in a metallic tone, and also to indicate colored display of the background part.

In this case, it is possible to create freely a combination of colors in which the regions for characters and the region for the background are displayed, respectively, by selecting the specified wavelength of a light component passing through the color filter 18, and the wavelengths of light components absorbed by the dichrotic dye dissolved in the guest host liquid crystals, respectively.

A case where the selective transmission color filter is used for the color filter 18 has been described in the foregoing by way of example, however, a dielectric multi layer film may be used instead.

The dielectric multi layer film is made by laminating a plurality of dielectrics having different refractive indices, and which

reflect a light component of incoming light at a specified wavelength while transmitting light components at other wavelengths.

Accordingly, if a color filter 18 made up of the dielectric multi layer film is disposed on the visible side of the absorption-type polarizing film 14, a light component of light falling on the liquid crystal display panel, at a specified wavelength only, is reflected by the color filter 18 made up of the dielectric multi layer film while light components at wavelengths other than the specified wavelength fall on the absorption-type polarizing film 14. Linearly polarized light having the polarized direction parallel with the transmission axis of the absorption-type polarizing film 14 then falls on the liquid crystal cell 12. In the background part behind the display parts, the linearly polarized light composed of the light components at wavelengths other than the specified wavelength undergoes phase modulation by 90° in the liquid crystal cell 12, and is also transmitted through the reflection-type polarizing film 16. On the other hand, in the display parts for characters and so forth, the linearly polarized light composed of the light components at wavelengths other than the specified wavelength is transmitted through the liquid crystal cell 12 without undergoing phase modulation as a voltage is applied between the electrodes of the liquid crystal cell 12, and undergoes specular reflection by the reflection-type polarizing film 16, being sent back to the visible side.

Therefore, in display regions for information such as characters, substantially all incoming light components are reflected, indicating bright display in a metallic tone. Meanwhile, in the background part behind the display regions, the background is seen colored, as a light

component at a specified wavelength only is reflected by the color filter 18 made up of the dielectric multi layer film, so that bright display in a metallic tone can be seen against the colored background.

With the use of the dielectric multi layer film, there will be little loss in the amount of light because of the makeup thereof. Also, it is possible to set freely the specified wavelength of a light component to be reflected by changing combinations of refractive indices of respective dielectric layers.

Further, a color polarizing film may be substituted for the color filter 18, and such an embodiment will be described in detail hereinafter.

Otherwise, a reflective color filter capable of transmitting a light component at a specified wavelength only, and reflecting light components at other wavelengths, a fluorescent filter having a function of converting the wavelength of incoming light, or so forth may be used instead.

Second Embodiment

Next, a second embodiment of a liquid crystal display device according to the invention is described with reference to Fig 11.

Fig. 11 is a schematic sectional view illustrating the construction of a liquid crystal display panel serving as the liquid crystal display device. Parts corresponding to those previously described with reference to Figs. 1 to 10 are denoted by the same reference numerals, and description thereof is omitted.

The construction of the liquid crystal display panel is the same as that shown in Fig. 1 except that a light absorption film 13 is

disposed on the side (the underside in the figure) of the reflection-type polarizing film 16 opposite from the visible side. A light absorption film colored in black, an absorption-type polarizing film, an absorption-type color filter, or the like may be used for the light film 13. In the case of using the absorption-type polarizing film, same is disposed such that the transmission axis thereof crosses that of the reflection-type polarizing film 16 at a right angle.

If the light absorption film 13 is disposed on the side of the reflection-type polarizing film 16, opposite from the visible side, light transmitted through the reflection-type polarizing film 16 can be absorbed by the light absorption film 13, so that the background part can be shown in a black or dark display condition for displaying information, indicating clearly colored display of characters and so forth in a metallic tone against the background.

As a result, contrast in display is improved. When display is inverted, various information such as time information and calendar information can be displayed with characters shown in black or in a color similar thereto in good contrast to the background shown in a bright and metallic tone.

In respect of other functions and application of various modifications, this embodiment is similar to the first embodiment, and therefore, description thereof is omitted.

Third Embodiment

Now, a third embodiment of a liquid crystal display device according to the invention is described with reference to Fig. 12.

Fig. 12 is a schematic sectional view illustrating the

construction of a liquid crystal display panel serving as the liquid crystal display device. Parts corresponding to those previously described with reference to Figs. 1 to 10 are denoted by the same reference numerals, and description thereof is omitted.

The construction of the liquid crystal display panel is the same as that shown in Fig. 1 except that a light scattering film 15 is disposed on the visible side (the upper side in the figure) of the absorption-type polarizing film 14.

The light scattering film 15 is formed by applying silica particles made of silicon dioxide, acrylic beads, or calcium powders that are mixed into an adhesive applied to a film-like substrate.

By installing the light scattering film 15 on the visible side of the absorption-type polarizing film 14, it is possible to cause light sent out to the visible side after specular reflection by the reflection-type polarizing film 16 to undergo irregular reflection by the agency of the light scattering film 15. As a result, a strong metallic tone in which colored display of time information and calendar information are indicated can be turned to a more delicate tone, allowing the display to be seen with more ease while widening a viewing angle as well.

A case where the light scattering film 15 is disposed on the visible side of the absorption-type polarizing film 14 is described in the foregoing by way of example, however, the light scattering film 15 may be disposed between the absorption-type polarizing film 14 and the liquid crystal cell 12, or between the liquid crystal cell 12 and the reflection-type polarizing film 16.

In respect of other functions and application of various modifications, this embodiment is similar to the first embodiment, and

description thereof is therefore omitted.

Fourth Embodiment

Now, a fourth embodiment of a liquid crystal display device according to the invention is described with reference to Fig 13. Fig. 13 is a schematic sectional view illustrating the construction of a liquid crystal display panel serving as the liquid crystal display. Parts corresponding to those previously described with reference to Figs. 1 to 12 are denoted by the same reference numerals, and description thereof is omitted.

The construction of the liquid crystal display panel is the same as that shown in Fig. 1 except that a light absorption film 13 is disposed on the side of the reflection-type polarizing film 16, opposite from the visible side, and a light scattering film 15 is disposed on the visible side of the absorption-type polarizing film 14.

The liquid crystal display panel according to this embodiment has a construction wherein both the light absorption film 13 of the liquid crystal display panel shown in Fig. 11, and the light scattering film 15 of the liquid crystal display panel shown in Fig. 12 are installed, and consequently is able to have the operation and beneficial effects of both the films.

That is, with the use of the liquid crystal display panel, contrast between character parts thereof and the background part for displaying information can be enhanced, and a metallic tone in which colored display is indicated can be turned to a more delicate tone, allowing the display to be seen with more ease while widening a viewing angle as well.

In respect of other functions and application of various modifications, this embodiment is similar to the first embodiment, and description thereof is therefore omitted.

Fifth Embodiment

Now, a fifth embodiment of a liquid crystal display device according to the invention is described with reference to Fig 14. Fig. 14 is a schematic sectional view illustrating the construction of a liquid crystal display panel serving as the liquid crystal display. Parts corresponding to those previously described with reference to Figs. 1 to 10 are denoted by the same reference numerals, and description thereof is omitted.

The construction of the liquid crystal display panel is the same as that shown in Fig. 1 except that a backlight 17 is disposed on the side (the underside in the figure) of the reflection-type polarizing film 16, opposite from the visible side.

An electroluminescence device, a light-emitting diode (LED) array, or a light source such as a cold cathode tube or a hot cathode tube is used for the backlight 17.

If the backlight 17 is disposed on the side of the reflection-type polarizing film 16 opposite from the visible side, a half of light emitted from the backlight 17 and falling on the reflection-type polarizing film 16 is transmitted therethrough, and turned to the linearly polarized light, falling on the liquid crystal cell 12. In the background part, the linearly polarized light undergoes phase modulation by 90° when passing through the liquid crystal cell 12, and colored by the color filter 18 transmitting a light component at a

specified wavelength only, thereby being sent out to the visible side after being transmitted through the absorption-type polarizing film 14.

In character parts for displaying various information such as time information and calendar information, the light linearly polarized turned from light emitted by the backlight, and falling on the liquid crystal cell 12 does not undergo phase modulation by the liquid crystal layer 3 as a voltage is applied between the electrodes of the liquid crystal cell 12, and has therefore the polarized direction orthogonal to the transmission axis of the absorption-type polarizing film 14, thus being absorbed by the absorption-type polarizing film 14.

Consequently, even at dark places where no or little external light is available, various information such as time information and calendar information can be displayed in black or in a dark color against the bright background by the effect of colored light transmitted by lighting up the backlight 17.

In respect of other functions and application of various modifications, this embodiment is similar to the first embodiment, and description of these aspects is therefore omitted.

Sixth Embodiment

Now, a sixth embodiment of a liquid crystal display device according to the invention is described with reference to Fig 15.

Fig. 15 is a schematic sectional view illustrating the construction of a liquid crystal display panel serving as the liquid crystal display device. Parts corresponding to those previously described with reference to Figs. 1 to 14 are denoted by the same

reference numerals, and description thereof is omitted.

The construction of the liquid crystal display panel is the same as that shown in Fig. 14 except that a translucent film 19 is disposed between the reflection-type polarizing film 16 and the backlight 17.

In this embodiment of the invention, an absorption-type polarizing film is adopted for the translucent film 19, and disposed such that the transmission axis thereof intersects that of the reflection-type polarizing film 16 at an angle of 75°.

If the translucent film 19 is disposed between the reflection-type polarizing film 16 and the backlight 17, a half of light transmitted through the reflection-type polarizing film 16 can be absorbed by the translucent film 19 when the backlight 17 is not lit up, thereby darkening the background part, so that contrast of displayed information can be enhanced.

On the other hand, when the backlight 17 is lit up at places where ambient external light is insufficient, the background part can be made brighter by light transmitted through the translucent film 19, and characters and so forth for displaying information can be indicated in black and darker display.

Consequently, whether the backlight 17 is lit up or not, contrast of display can be enhanced.

In respect of other functions and application of various modifications, this embodiment is similar to the first embodiment and the fifth embodiment, and description of these aspects is therefore omitted.

Seventh Embodiment

Now, a seventh embodiment of a liquid crystal display device according to the invention is described with reference to Fig. 16. Fig. 16 is a schematic sectional view illustrating the construction of a liquid crystal display panel serving as the liquid crystal display device. Parts corresponding to those previously described with reference to Figs. 1 to 14 are denoted by the same reference numerals, and description thereof is omitted.

The construction of the liquid crystal display panel is the same as that shown in Fig. 14 except that a light scattering film 15 is disposed on the visible side of the absorption-type polarizing film 14.

By installing the light scattering film 15 on the visible side of the absorption-type polarizing film 14, it is possible to cause light outgoing to the visible side after specular reflection by the absorption-type polarizing film 14 to undergo irregular reflection by the agency of the light scattering film 15. As a result, a colored metallic tone in which characters and so forth expressing information are displayed can be turned to a more delicate tone, causing the display to be seen with more ease while widening a viewing angle as well.

In respect of other functions and application of various modifications, this embodiment is similar to the first embodiment and the fifth embodiment, and description of these aspects is therefore omitted.

Eighth Embodiment

Now, an eighth embodiment of a liquid crystal display device according to the invention is described with reference to Fig 17. Fig.

17 is a schematic sectional view illustrating the construction of a liquid crystal display panel serving as the liquid crystal display device. Parts corresponding to those previously described with reference to Figs. 1 to 16 are denoted by the same reference numerals, and description thereof is omitted.

The construction of the liquid crystal display panel is the same as that shown in Fig. 15 except that a light scattering film 15 is disposed on the visible side of the absorption-type polarizing film 14.

By installing the light scattering film 15 on the visible side of the absorption-type polarizing film 14, it is possible to cause light outgoing to the visible side after specular reflection by the absorption-type polarizing film 14 to undergo irregular reflection by the agency of the light scattering film 15. As a result, a colored metallic tone in which characters and so forth expressing information are displayed can be turned to a more delicate tone, causing the display to be seen with more ease while widening a viewing angle as well.

In respect of other functions and application of various modifications, this embodiment is similar to the first embodiment and the sixth embodiment, and description of these aspects is therefore omitted.

Ninth Embodiment

Now, a ninth embodiment of a liquid crystal display device according to the invention is described with reference to Figs. 18 and 19. Figs. 18 and 19 are schematic sectional views illustrating the construction of a liquid crystal display panel serving as the liquid

crystal display device, and the principles of colored display thereby. Parts corresponding to those previously described with reference to Figs. 1 to 11 are denoted by the same reference numerals, and description thereof is omitted. In Figs. 18 and 19, the direction of stripes on respective polarizing films and significance of respective solid lines with an arrow or arrows are same as described with reference to Figs. 9 and 10.

The construction of the liquid crystal display panel is the same as that shown in Fig. 11 except that a color polarizing film 28 serving as a color filter is disposed between the absorption-type polarizing film 14 and the liquid crystal cell 12 in place of the selective transmission color filter 18.

The color polarizing film 28 is capable of transmitting a light component of linearly polarized light in the direction orthogonal to the transmission axis of the color polarizing film 28, at a specified wavelength only, and absorbing light components of the linearly polarized light, at other wavelengths. However, the color polarizing film 28 has an optical property of transmitting both a light component of linearly polarized light in the direction parallel with the transmission axis thereof, at a specified wavelength, and light components of the linearly polarized light at other wavelengths.

In this case, the color polarizing film 28 is disposed such that the transmission axis thereof crosses that of the absorption-type polarizing film 14 at a right angle.

In this embodiment of the invention, the absorption-type polarizing film 14, the color polarizing film 28, and the liquid crystal cell 12 are disposed in this order.

Accordingly, since light transmitted through the absorption-type polarizing film 14 is the light linearly polarized in the direction orthogonal to the transmission axis of the color polarizing film 28, a light component thereof, at a specified wavelength only, is transmitted through the color polarizing film 28. However, light components of the linearly polarized light transmitted through the absorption-type polarizing film 14 at other wavelengths are absorbed by the color polarizing film 28. In the case of the example shown in the figures, the specified wavelength is that of a light component in yellow.

Fig. 18 shows the optical path of light components falling from the visible side onto the liquid crystal display panel, other than the light component in yellow, and Fig. 19 shows the optical path of the light component in yellow. The left half part of the figures indicates an OFF state where no voltage is applied between the electrodes of the liquid crystal cell 12, and the right half part thereof indicates an ON state where a voltage is applied between the electrodes of the liquid crystal cell 12.

As shown in Fig. 18, the light components falling from the visible side onto the liquid crystal display panel, other than the light component in yellow, are transmitted through the absorption-type polarizing film 14 and turned to linearly polarized light in the direction parallel with the transmission axis of the absorption-type polarizing film 14 (parallel with the plane of the figure), then falling on the color polarizing film 28. Since the direction of the oscillation plane thereof crosses the transmission axis of the color polarizing film 28 at a right angle, all the light components described above are absorbed by the color polarizing film 28, thus making no contribution

to display regardless of whether the liquid crystal cell 12 is in the ON state or the OFF state.

As shown in Fig. 19, the light component in yellow falling from the visible side onto the liquid crystal display panel is transmitted through the absorption-type polarizing film 14 and turned to linearly polarized light in the direction parallel with the transmission axis of the absorption-type polarizing film 14, then falls on the color polarizing film 28 as with the case of the light components other than the light component in yellow. However, although the direction of polarization thereof is orthogonal to the transmission axis of the color polarizing film 28, linearly polarized light in yellow can be transmitted through the color polarizing film 28, and falls unaltered on the liquid crystal cell 12.

In the background part where the liquid crystal cell 12 is in the OFF state, the linearly polarized light in yellow falling on the liquid crystal cell 12 undergoes phase modulation by 90° when transmitted through the liquid crystal cell 12, and the direction of the polarization thereof is caused to turn parallel with (perpendicular to the plane of the figure) the transmission axis of the reflection-type polarizing film 16. As a result, the linearly polarized light in yellow is transmitted through the reflection-type polarizing film 16, and absorbed by the light absorption film 13 disposed behind the reflection-type polarizing film 16. From the visible side, therefore, display is seen in a black or darker tone.

On the other hand, in display parts for characters and so forth, where the liquid crystal cell 12 is in the ON state, the linearly polarized light in yellow falling unaltered on the liquid crystal cell 12

is transmitted therethrough, without undergoing phase modulation, and falls on the reflection-type polarizing film 16. Consequently, the linearly polarized light in yellow in the direction orthogonal to the transmission axis of the reflection-type polarizing film 16 undergoes specular reflection by the reflection-type polarizing film 16, outgoing to the visible side along the optical path thereof in the reverse direction.

It follows that in regions for characters and so forth for displaying information, substantially all the light component in yellow, falling on the liquid crystal cell 12, is reflected, indicating bright display in a colored (yellow) and metallic tone against the background part in a black or darker tone.

Consequently, in marked contrast to conventional electronic equipment for displaying various information such as time information and calendar information in black against the background in white, the liquid crystal display panel, even if used as a display device of electronic equipment, will be able to have variation in design, and be a lot of fun to use.

By selecting a specified wavelength (that is, a color) of a light component to be transmitted through the color polarizing film 28, display in a metallic tone can be executed in various colors.

Tenth Embodiment

Now, a tenth embodiment of a liquid crystal display device according to the invention is described with reference to Figs. 20 and 21. Figs. 20 and 21 are schematic sectional views illustrating the construction of a liquid crystal display panel serving as the liquid

crystal display device and the principles of colored display thereby. Parts corresponding to those previously described with reference to Figs. 1 to 11 are denoted by the same reference numerals, and description thereof is omitted. In Figs. 20 and 21, the direction of stripes on respective polarizing films and significance of respective solid lines with an arrow or arrows are same as described with reference to Figs. 9 and 10.

The construction of the liquid crystal display panel is the same as that shown in Figs. 18 and 19 except that a color polarizing film 28 serving as a color filter is disposed between the liquid crystal cell 12 and the reflection-type polarizing film 16.

The color polarizing film 28 according to this embodiment as well is capable of transmitting a component of linearly polarized light in the direction orthogonal to the transmission axis thereof, at a specified wavelength (in yellow, in this case) only, and absorbing light components of the linearly polarized light at other wavelengths (in colors other than yellow).

As shown in Figs. 20 and 21, all light components falling from the visible side onto the liquid crystal display panel are transmitted through the absorption-type polarizing film 14, and turned to linearly polarized light in the direction parallel with the transmission axis of the absorption-type polarizing film 14 (parallel with the plane of the figure), then falling on the liquid crystal cell 12. The linearly polarized light undergoes phase modulation by 90° in the left half part of the figures, where the liquid crystal cell 12 is in an OFF state, when transmitted through the liquid crystal cell 12, and turned to linearly polarized light in the direction parallel with the transmission axis of

the color polarizing film 28, falling then on the color polarizing film 28.

Accordingly, in the background part where the liquid crystal cell 12 is in the OFF state, both the light component in yellow and the light components in colors other than yellow are transmitted through the color polarizing film 28 as well as the reflection-type polarizing film 16 disposed such that the transmission axis thereof is parallel with that of the color polarizing film 28, and are absorbed by the light absorption film 13 as shown in Figs. 20 and 21.

In display regions for characters and so forth, where the liquid crystal cell 12 is in an ON state, the light components in colors other than yellow are absorbed by the color polarizing film 28 as shown in Fig. 20. However, the light component in yellow is transmitted through the color polarizing film 28, and falls on the reflection-type polarizing film 16, whereupon the light component in yellow undergoes mirror reflection, by the reflection-type polarizing film 16 because the direction of linear polarization thereof crosses the transmission axis of the reflection-type polarizing film 16 at a right angle, outgoing to the visible side along the optical path thereof in the reverse direction. Consequently, substantially all the colored light component after falling on the liquid crystal cell 12 will be reflected, outgoing to the visible side.

It follows therefore that the use of the liquid crystal display panel can also provide bright display of various information such as time information and calendar information in a colored and metallic tone against the background seen in a black or darker tone.

Consequently, in marked contrast to conventional electronic

equipment for displaying various information such as time information and calendar information in black against the background in white, the liquid crystal display panel used as a display device of electronic equipment will be able to have variation in design, and be a lot of fun to use.

Furthermore, by selecting a specified wavelength (that is, a color) of a light component to be transmitted through the color polarizing film 28, display in a metallic tone can be executed in various colors.

With the ninth and the tenth embodiment of the liquid crystal display panel according to the invention, as described in the foregoing, the color polarizing film 28 may be disposed on the visible side of the absorption-type polarizing film 14, or on the inner surface side of either of the electrodes inside the liquid crystal cell 12 as with the case of the color filter 18 described in connection with the first embodiment.

Furthermore, various alternatives to the color filter 18, as described in connection with the first embodiment, are also applicable to the ninth and the tenth embodiment of the liquid crystal display panel described above.

INDUSTRIAL APPLICABILITY

As is evident from the foregoing description, with the liquid crystal display device according to the invention, display of various information can be indicated in a bright relief in a colored metallic tone against a dark background, or conversely, the display can be indicated in a black or dark color against a background shown in a

colored metallic tone, thus enabling suitable selection of a color in which the display is to be indicated.

Thus, in marked contrast to conventional timepieces or other electronic equipment for displaying information such as time information and calendar information in black against the background in white, the use of the liquid crystal display device (liquid crystal display panel) as a display panel of various electronic equipment can provide display of colorful variation in design, and offering some fun of use.

Further, the liquid crystal display device according to the invention are applicable to a liquid crystal display device with a backlight, which can be put to use at dark places where little or no external light is available.

The scope of the invention is not limited to a liquid crystal display device for digitally displaying time information and calendar information or numerical information by use of numbers, but includes a liquid crystal display device wherein a liquid crystal display panel of the dot-matrix display mode is adopted for the liquid crystal display panel described above to display arbitrary characters or graphics, or an electrode of a liquid crystal cell is formed to be a number of graphic patterns which are displayed selectively.